

Chapter 5

Summary Of Forecast Verification

5.1 ANNUAL FORECAST VERIFICATION

Verification of warning positions and intensities at initial, 12-, 24-, 48-, and 72-hour forecast periods was made against the final best track. The (scalar) track forecast, along-track and cross-track errors (illustrated in Figure 5-1) were calculated for each verifying JTWC forecast. These data, in addition to a detailed summary for each tropical cyclone, are included as Chapter 6. This section summarizes verification data for 1998 and contrasts it with annual verification statistics from previous years.

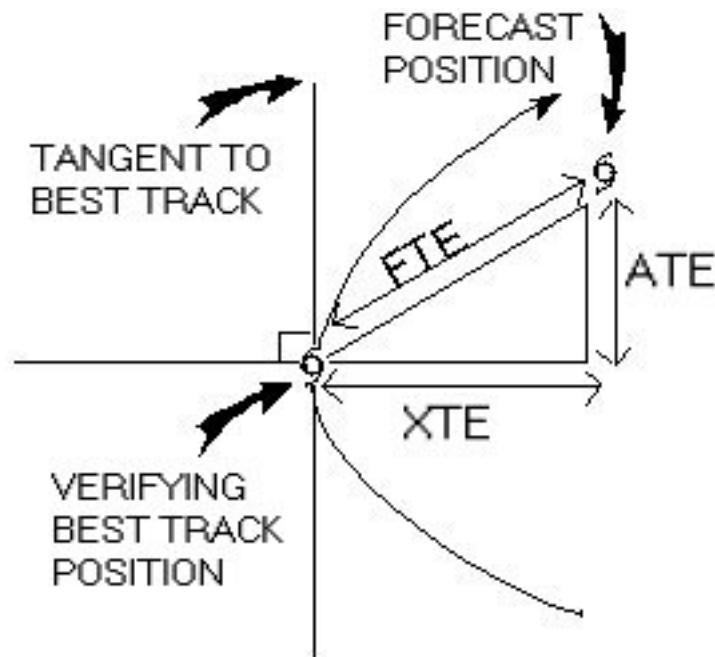


Figure 5-1. Definition of cross-track error (XTE), along-track error (ATE) and forecast track error (FTE). In this example, the forecast position is ahead of and to the right of the verifying best track position. Therefore, the XTE is positive (to the right of the best track) and the ATE is positive (ahead or faster than the best track). Adapted from Tsui and Miller, 1988.

5.1.1 NORTHWEST PACIFIC OCEAN

The frequency distributions of errors for initial warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-2a through 5-2f. Table 5-1 includes mean track, along-track and cross-track errors for 1984-1998. Figure 5-3 shows mean track errors and a 5-year running mean of track errors at 24-, 48- and 72-hours since 1974. Table 5-2 lists annual mean track errors from 1959, when JTWC was founded, until the present.

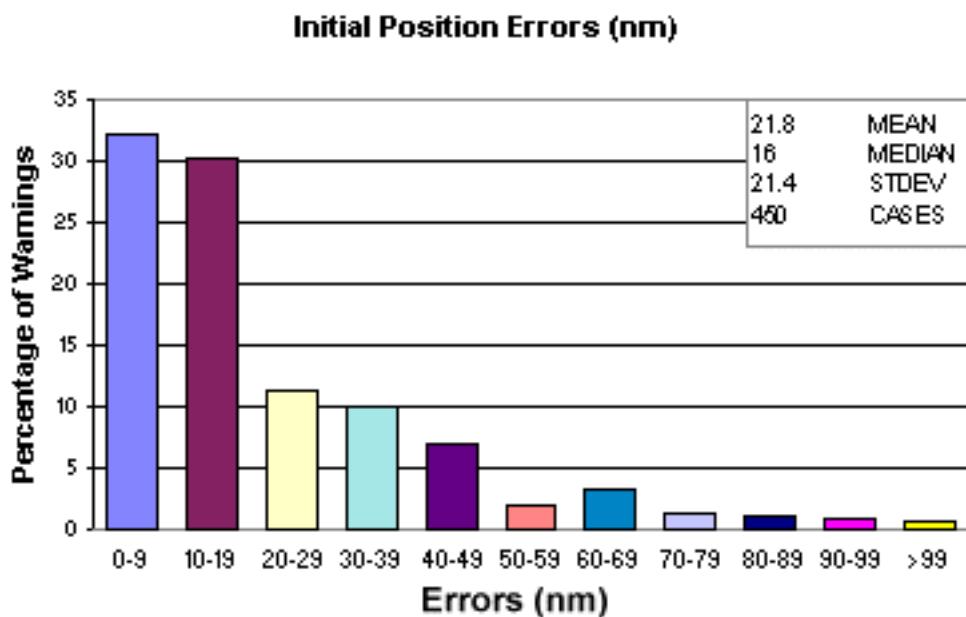


Figure 5-2a. Frequency distribution of initial warning position errors (10 nm increments) for the North West Pacific Ocean tropical cyclones in 1998.

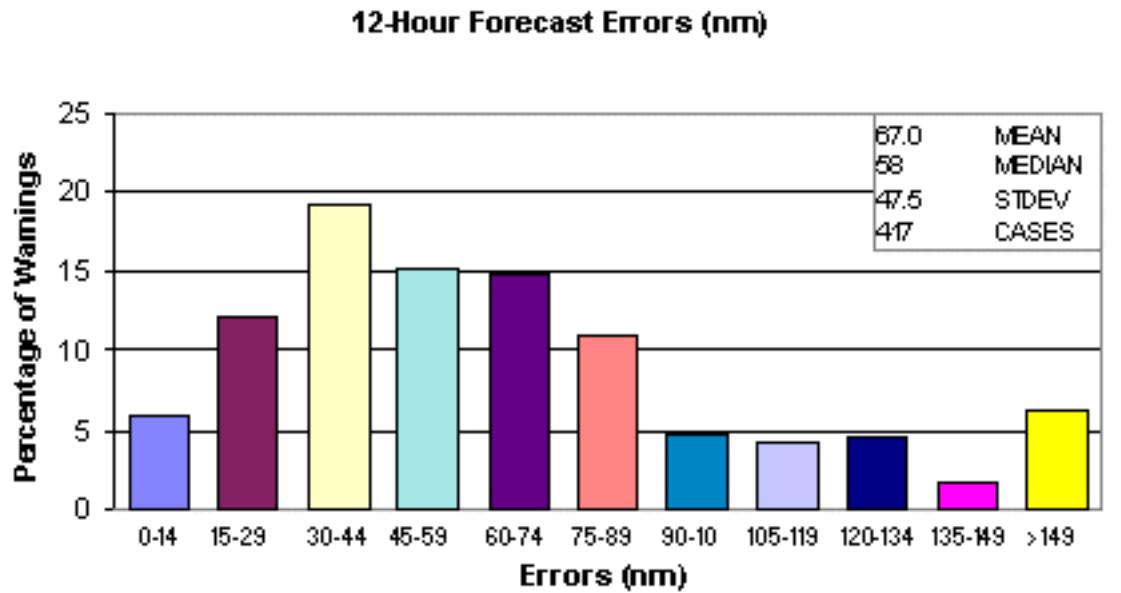


Figure 5-2b. Frequency distribution of 12-hour track forecast errors (15 nm increments) for the North West Pacific Ocean tropical cyclones in 1998.

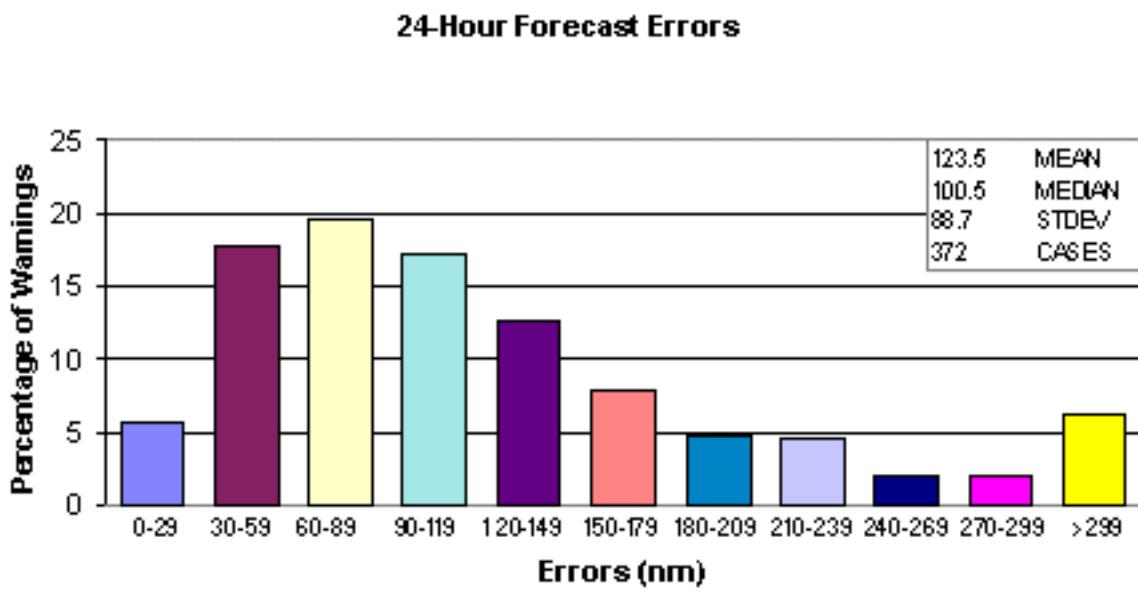


Figure 5-2c. Frequency distribution of 24-hour track forecast errors (30 nm increments) for the North West Pacific Ocean tropical cyclones in 1998.

36-Hour Forecast Errors

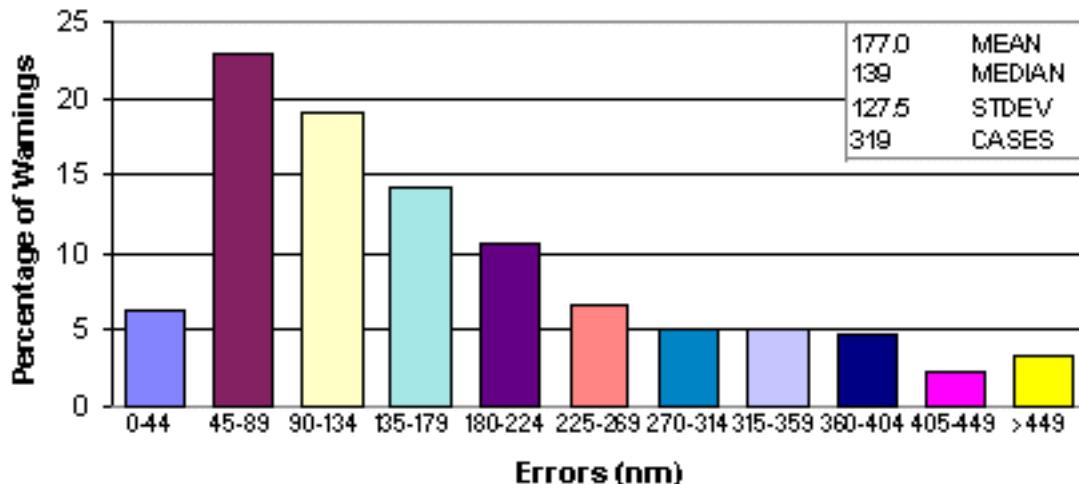


Figure 5-2d. Frequency distribution of 36-hour track forecast errors (45 nm increments) for the North West Pacific Ocean tropical cyclones in 1998.

48-Hour Forecast Errors

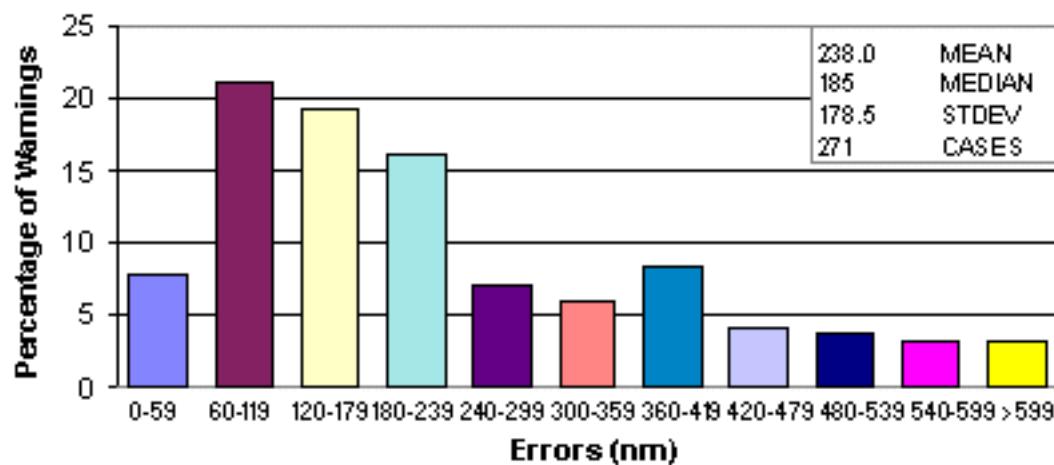


Figure 5-2e. Frequency distribution of 48-hour track forecast errors (60 nm increments) for the North West Pacific Ocean tropical cyclones in 1998.

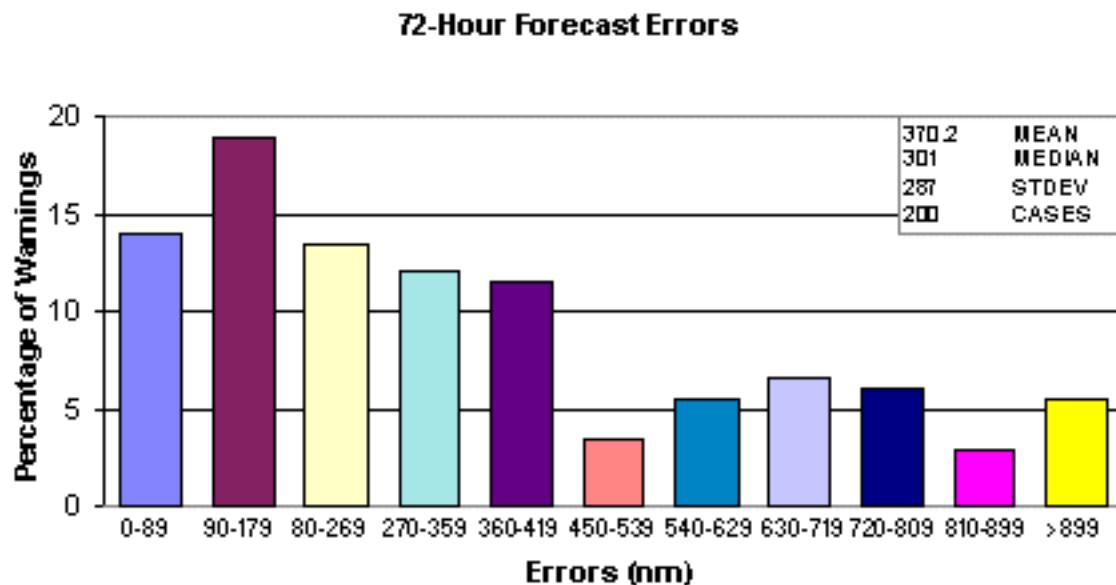


Figure 5-2f. Frequency distribution of 72-hour track forecast errors (90 nm increments) for the North West Pacific Ocean tropical cyclones in 1998.

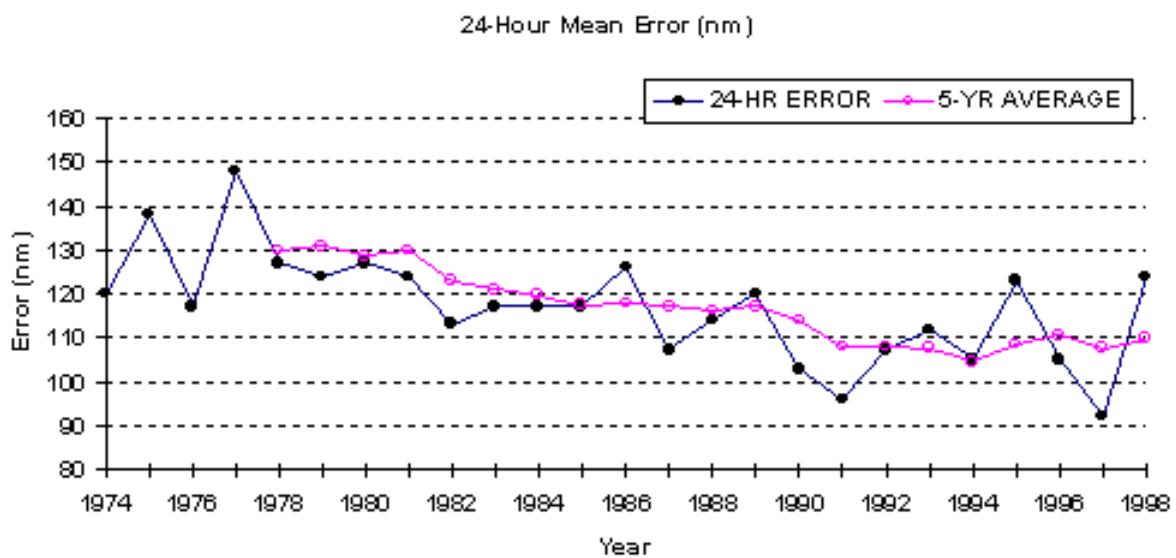


Figure 5-3a. Mean track forecast error (nm) and 5-year running mean for 24 hours for Northern Pacific Ocean tropical cyclones from 1974-1998.

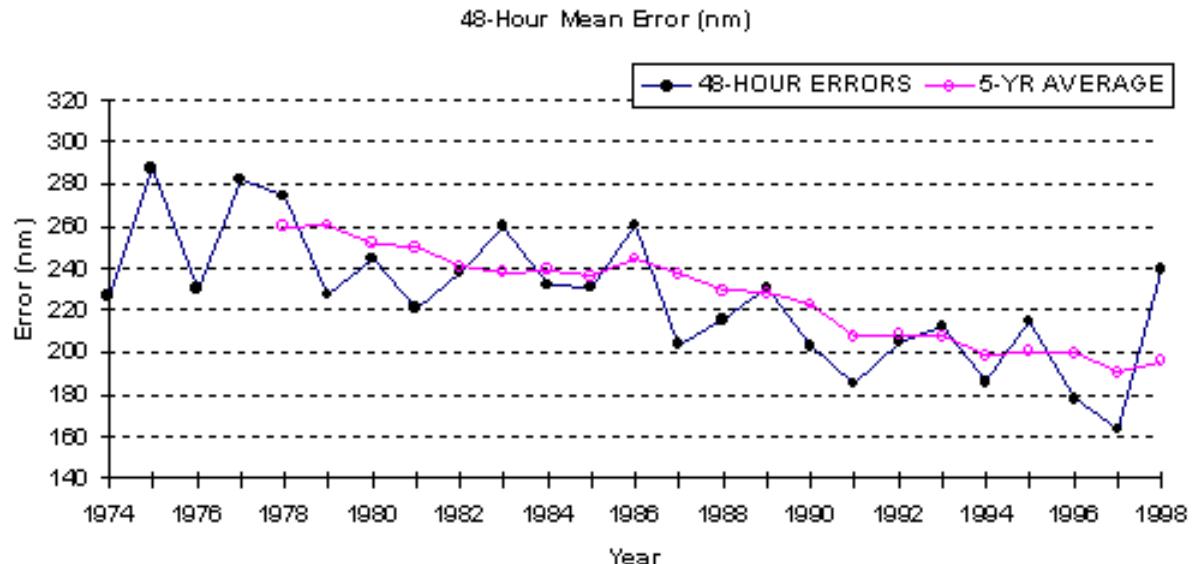


Figure 5-3b. Mean track forecast error (nm) and 5-year running mean for 48 hours for Northern Pacific Ocean tropical cyclones from 1974-1998.

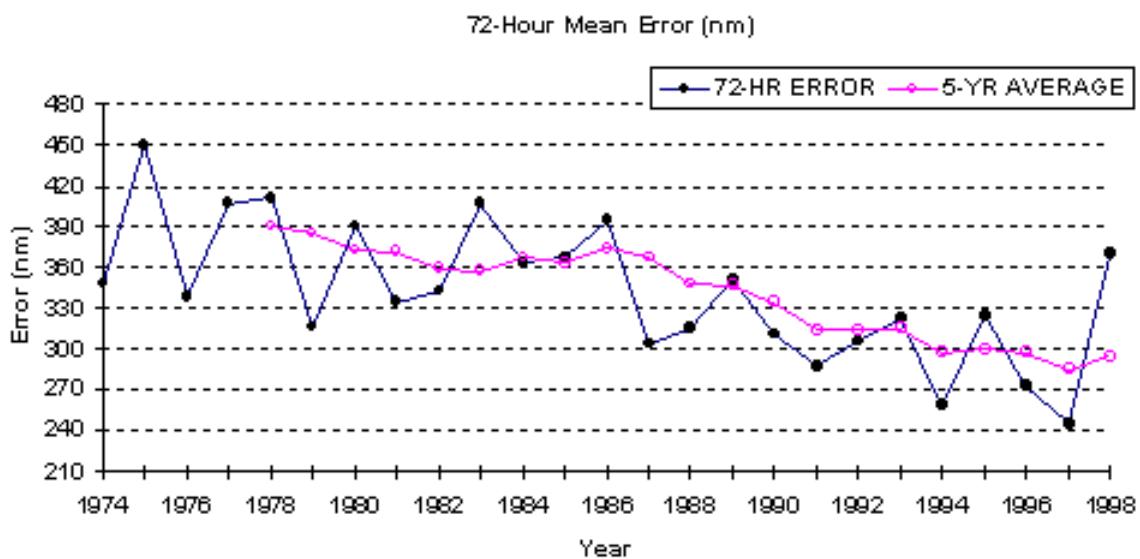


Figure 5-3c. Mean track forecast error (nm) and 5-year running mean for 72 hours for Northern Pacific Ocean tropical cyclones from 1974-1998.

Table 5-1 INITIAL POSITION AND FORECAST ERRORS (NM) FOR THE WESTERN NORTH PACIFIC 1984-1998

	Initial Position		24-Hour				48-Hour				72-Hour			
	Number	Error	Number	Track	Along	Cross	Number	Track	Along	Cross	Number	Track	Along	Cross
1984	611	22	492	117	84	64	378	232	163	131	286	363	238	216
1985	592	18	477	117	80	68	336	231	153	138	241	367	230	227
1986	743	21	645	126	85	70	535	261	183	151	412	394	276	227
1987	657	18	563	107	71	64	465	204	134	127	389	303	198	186
1988	465	23	373	114	85	58	262	216	170	103	183	315	244	159
1989	710	20	625	120	83	69	481	231	162	127	363	350	265	177
1990	794	21	658	103	72	60	525	203	148	110	432	310	225	168
1991	835	22	733	96	69	53	599	185	137	97	484	287	229	146
1992	941	25	841	107	77	59	687	205	143	116	568	305	210	172
1993	853	26	725	112	79	63	570	212	151	117	437	321	226	173
1994	1058	24	932	98	85	62	753	176	158	105	608	242	218	144
1995	559	29	539	123	89	67	421	215	159	117	319	325	240	167
1996	922	25	880	105	76	56	711	178	134	89	607	272	203	137
1997	910	20	865	93	76	55	752	164	134	87	642	245	202	120
1998	450	22	375	124	98	58	273	239	178	127	202	370	274	201
15Yr														
Avg	740	22	648	111	81	62	517	210	154	116	412	318	232	175

Table 5-2 MEAN FORECAST TRACK ERRORS (NM) FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES FOR 1959-1998

YEAR (Notes)	24-HOUR			48-HOUR			72-HOUR					
	TY (1)	TC (3)	CRS	ALNG	TY (1)	TC (3)	CRS	ALNG	TY (1)	TC (3)	CRS	ALNG
			TRK (2)	TRK (2)			TRK (2)	TRK (2)			TRK (2)	TRK (2)
1959	117*				267*							
1960	177*				354*							
1961	136				274							
1962	144				287				476			
1963	127				246				374			
1964	133				284				429			
1965	151				303				418			
1966	136				280				432			
1967	125				276				414			
1968	105				229				337			
1969	111				237				349			
1970	98	104			181	190			272	279		
1971	99	111	64		203	212	118		308	317	177	
1972	116	117	72		245	245	146		382	381	210	
1973	102	108	74		193	197	134		245	253	162	
1974	114	120	78		218	226	157		357	348	245	
1975	129	138	84		279	288	181		442	450	290	
1976	117	117	71		232	230	132		336	338	202	
1977	140	148	83		266	283	157		390	407	228	
1978	120	127	71	87	241	271	151	194	459	410	218	296
1979	113	124	76	81	219	226	138	146	319	316	182	214

1. Forecasts were verified for typhoons when intensities were at least 35kt at warning times

2. Cross-track and along-track errors were adopted by the JTWC in 1986. Right angle errors (used prior to 1986) were recomputed as cross-track errors after-the fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track.

3. Mean forecast errors for all warned systems in Northwest Pacific.

*Forecast positions north of 35 degrees North latitude were not verified.

**1994 statistics were recalculated to resolve earlier Along and Cross-Track discrepancies.

Table 5-2 MEAN FORECAST TRACK ERRORS (NM) FOR
WESTERN NORTH PACIFIC TROPICAL CYCLONES FOR
1959-1998 (continued)

YEAR (Notes)	24-HOUR			48-HOUR			72-HOUR			CRS TRK (2)	ALNG TRK (2)	
	TY (1)	TC (3)	CRS TRK (2)	TY (1)	TC (3)	CRS TRK (2)	TY (1)	TC (3)	CRS TRK (2)			
1980	116	126	76	86	221	243	147	165	362	389	230	266
1981	117	124	77	80	215	221	131	146	342	334	219	206
1982	114	113	70	74	229	238	142	162	337	342	211	223
1983	110	117	73	76	247	260	164	169	384	407	263	259
1984	110	117	64	84	228	232	131	163	361	363	216	238
1985	112	117	68	80	228	231	138	153	355	367	227	230
1986	117	126	70	85	261	261	151	183	403	394	227	276
1987	101	107	64	71	211	204	127	134	318	303	186	198
1988	107	114	58	85	222	216	103	170	327	315	159	244
1989	107	120	69	83	214	231	127	162	325	350	177	265
1990	98	103	60	72	191	203	110	148	299	310	168	225
1991	93	96	53	69	187	185	97	137	298	287	146	229
1992	97	107	59	77	194	205	116	143	295	305	172	210
1993	102	112	63	79	205	212	117	151	320	321	173	226
1994**	96	105	56	76	172	186	105	131	244	258	152	176
1995	105	123	67	89	200	215	117	159	311	325	167	240
1996	85	105	56	76	157	178	89	134	252	272	137	203
1997	86	93	55	76	159	164	87	134	251	245	120	202
1998	127	124	58	98	263	239	127	178	392	370	201	274
Averages	108	108	63	73	217	209	121	141	331	314	182	213

1. Forecasts were verified for typhoons when intensities were at least 35kt at warning times

2. Cross-track and along-track errors were adopted by the JTWC in 1986. Right angle errors (used prior to 1986) were recomputed as cross-track errors after-the fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track.

3. Mean forecast errors for all warned systems in Northwest Pacific.

*Forecast positions north of 35 degrees North latitude were not verified.

**1994 statistics were recalculated to resolve earlier Along and Cross-Track discrepancies.

5.1.2 NORTH INDIAN OCEAN

The frequency distributions of errors for warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-4a through 5-4f. Table 5-3 includes mean track, along-track and cross-track errors for 1984-1998. Figure 5-5 shows mean track errors and a 5-year running mean of track errors at 24-, 48- and 72-hours since 1981.

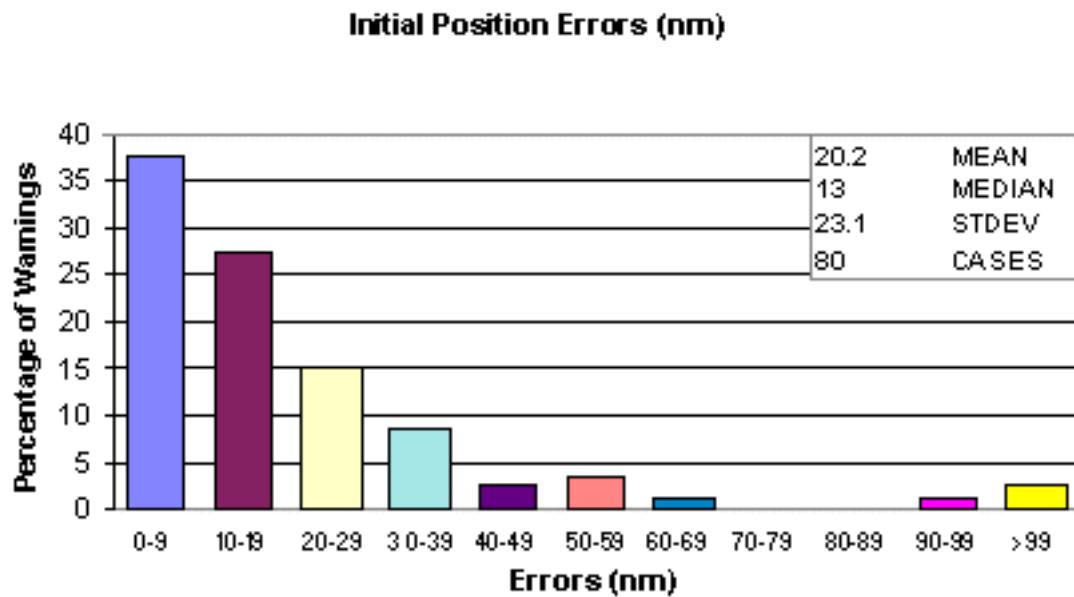


Figure 5-4a. Frequency distribution of initial warning position errors (10 nm increments) for the North Indian Ocean tropical cyclones in 1998.

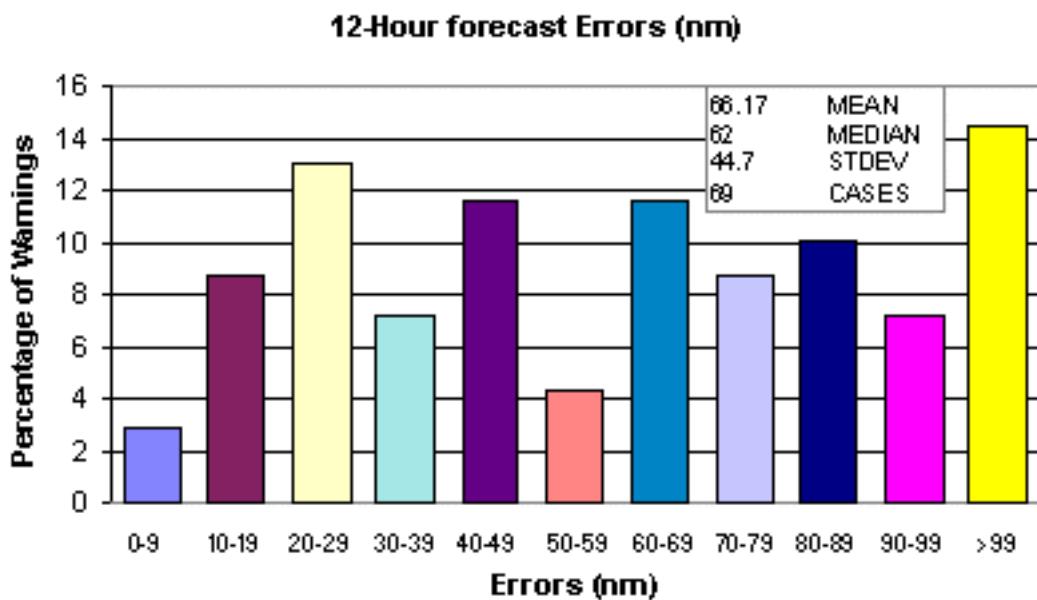


Figure 5-4b. Frequency distribution of 12-hour track forecast errors (10 nm increments) for the North Indian Ocean tropical cyclones in 1998.

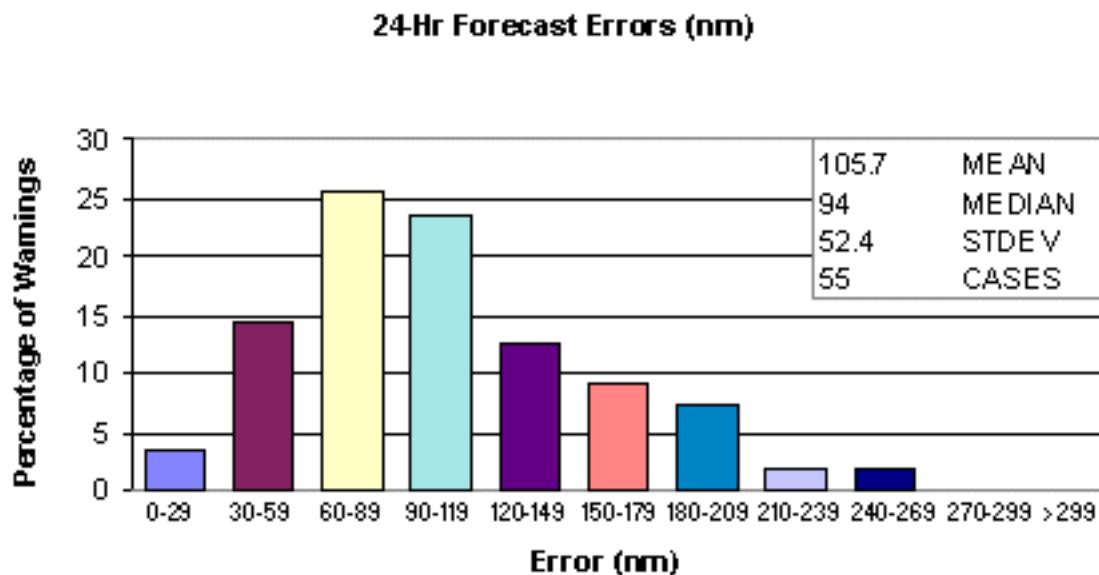


Figure 5-4c. Frequency distribution of 24-hour track forecast errors (30 nm increments) for the North Indian Ocean tropical cyclones in 1998.

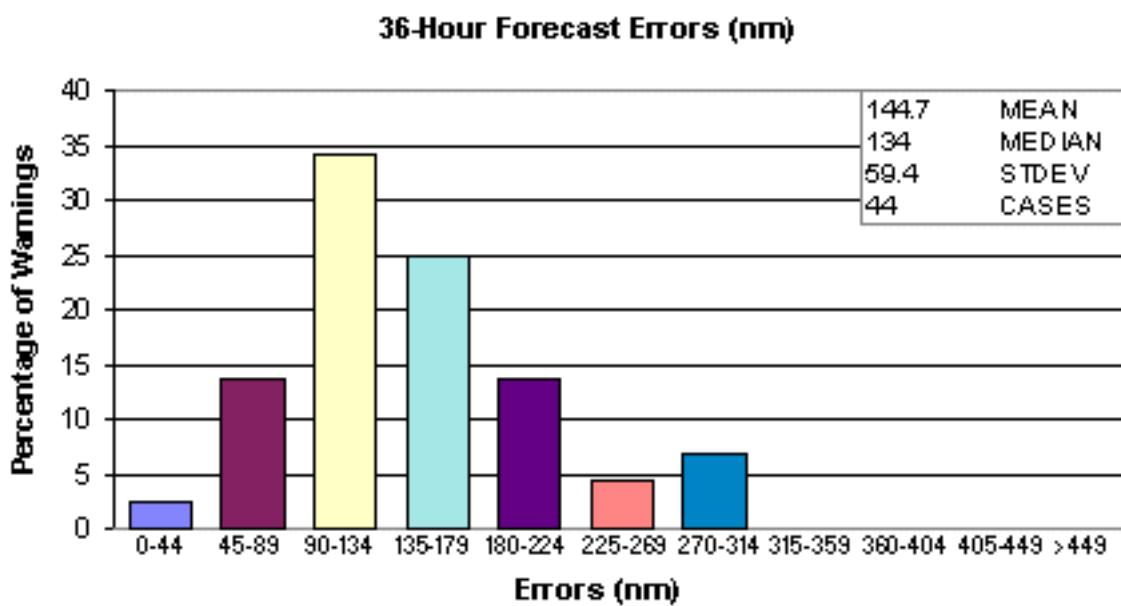


Figure 5-4d. Frequency distribution of 36-hour track forecast errors (45 nm increments) for the North Indian Ocean tropical cyclones in 1998.

48-Hour Forecast Errors (nm)

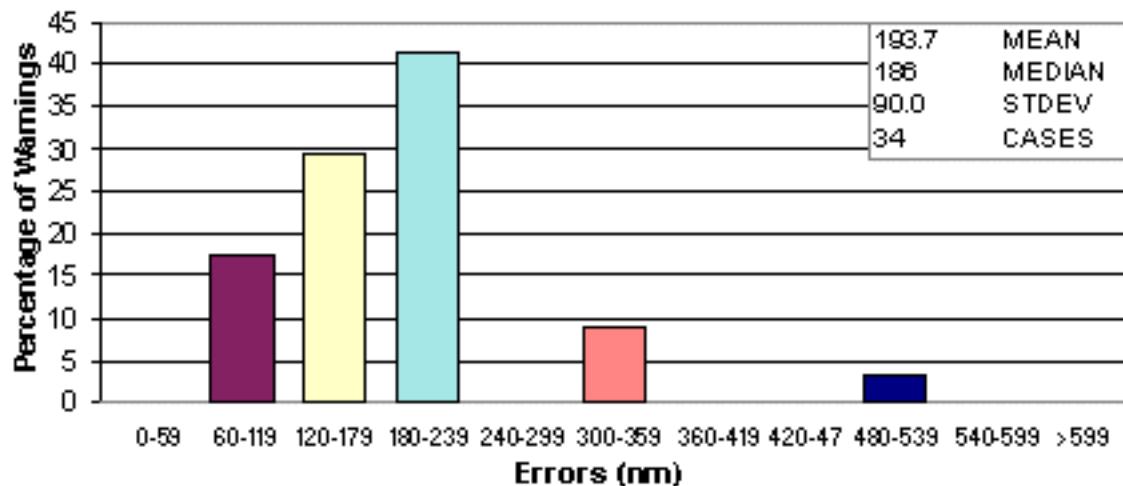


Figure 5-4e. Frequency distribution of 48-hour track forecast errors (60 nm increments) for the North Indian Ocean tropical cyclones in 1998.

72-Hour Forecast Errors (nm)

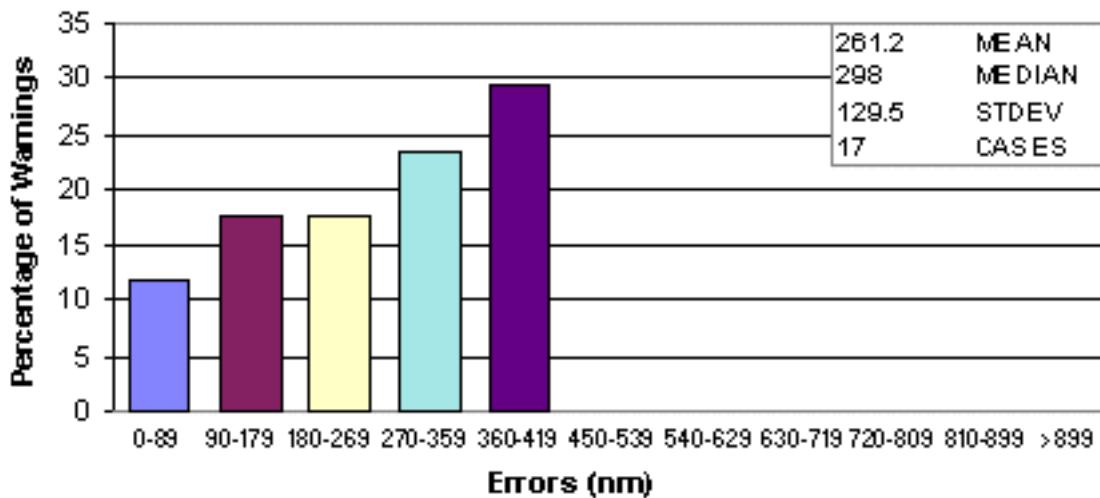


Figure 5-4f. Frequency distribution of 72-hour track forecast errors (90 nm increments) for the North Indian Ocean tropical cyclones in 1998.

Table 5-3 JTWC INITIAL POSITION AND FORECAST ERRORS (NM) FOR THE NORTHERN INDIAN OCEAN 1984-1998

	Initial Position		24-Hour				48-Hour				72-Hour			
	Number	Error	Number	Track	Along	Cross	Number	Track	Along	Cross	Number	Track	Along	Cross
	1985	53	31	30	122	102	53	8	242	119	194	0		
1986	28	52	16	134	118	53	7	168	131	80	5	269	189	180
1987	83	42	54	144	97	100	25	205	125	140	21	305	219	188
1988	44	34	30	120	89	63	18	219	112	176	12	409	227	303
1989	44	19	33	88	62	50	17	146	94	86	12	216	164	11
1990	46	31	36	101	85	43	24	146	117	67	17	185	130	104
1991	56	38	43	129	107	54	27	235	200	89	14	450	356	178
1992	191	35	149	128	73	86	100	244	141	166	62	398	276	218
1993	36	27	28	125	87	79	20	198	171	74	12	231	176	116
1994	60	25	44	97	80	44	28	153	124	63	13	213	177	92
1995	54	30	47	138	119	58	32	262	247	77	20	342	304	109
1996	135	33	123	134	94	80	85	238	181	127	58	311	172	237
1997	56	29	42	119	87	49	29	201	168	92	17	228	195	110
1998	80	20	55	106	84	51	34	198	135	106	17	262	188	144
15-Yr														
Avg	69	32	51	123	94	62	32	209	152	112	21*	273*	198*	142*

*14 year average (1985 not available)

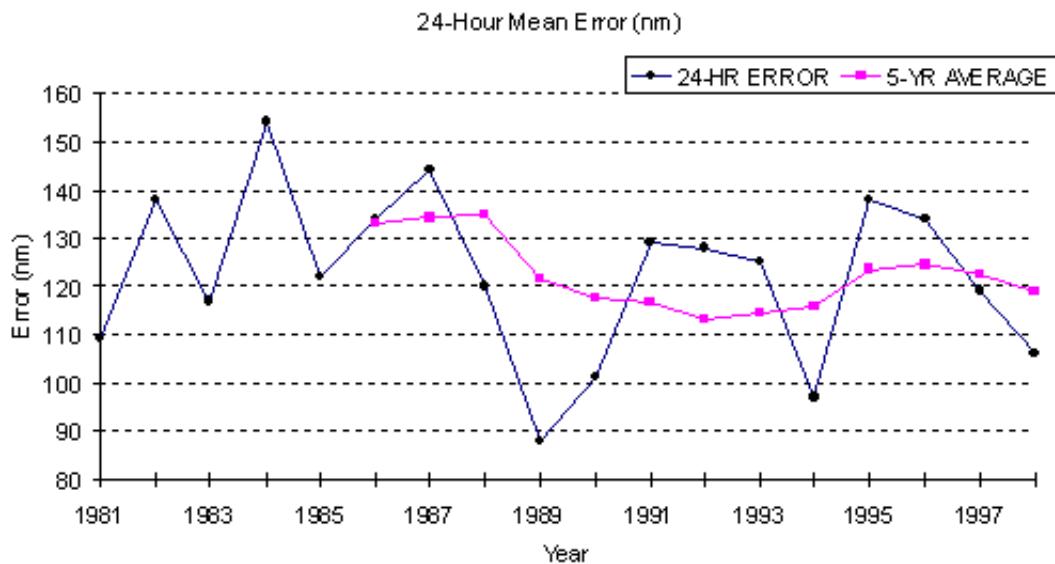


Figure 5-5a. Mean track forecast error (nm) and 5-year running mean for 24 hours for Northern Indian Ocean tropical cyclones from 1981-1998.

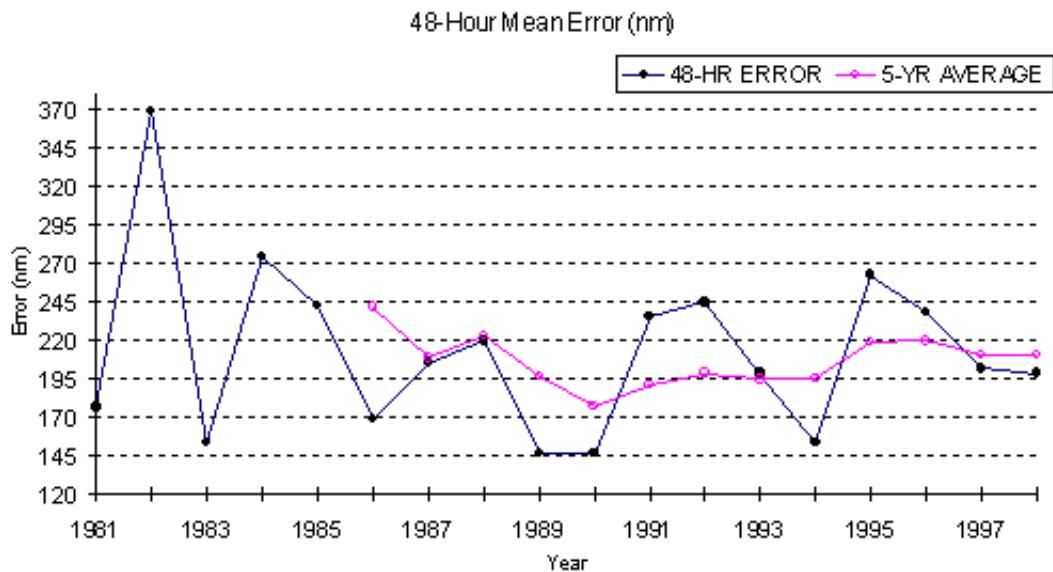


Figure 5-5b. Mean track forecast error (nm) and 5-year running mean for 48 hours, for Northern Indian Ocean tropical cyclones from 1981-1998.

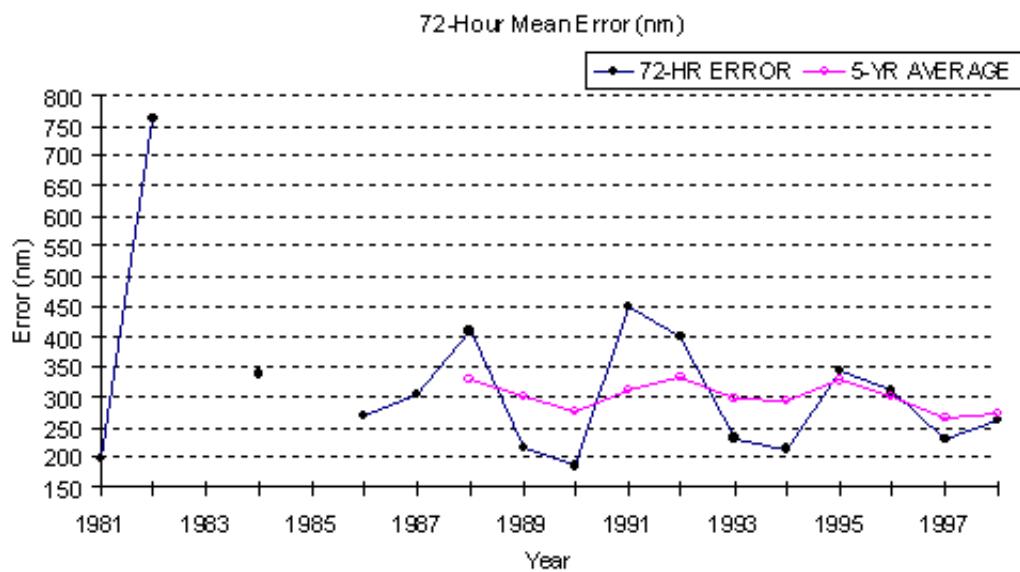


Figure 5-5c. Mean track forecast error (nm) and 5-year running mean for 72 hours for Northern Indian Ocean tropical cyclones from 1981-1998. The data breaks in the chart are due to no 72 hour forecasts during the year.

5.1.3 SOUTH PACIFIC AND SOUTH INDIAN OCEANS

The frequency distributions of errors for warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-6a through 5-6f. Table 5-4 includes mean track, along-track and cross-track errors for 1984-1998. Figure 5-7 shows mean track errors and a 5-year running mean of track errors at 24-, 48- and 72-hours from 1981-1998.

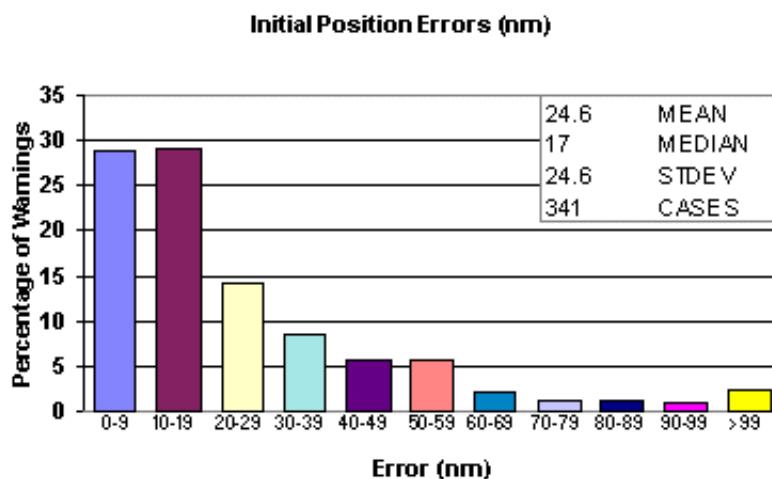


Figure 5-6a. Frequency distribution of initial warning position errors (10 nm increments) for Southwest Pacific and South Indian Ocean tropical cyclones in 1998.

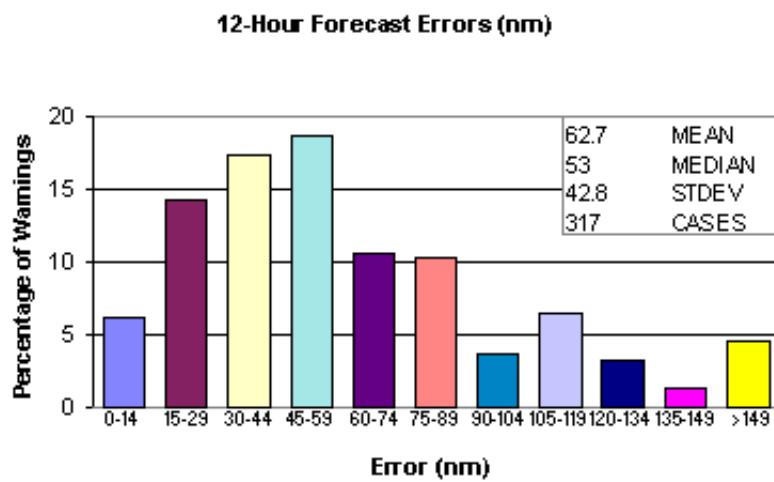


Figure 5-6b. Frequency distribution of 12-hour forecast errors (15 nm increments) for Southwest Pacific and South Indian Ocean tropical cyclones in 1998.

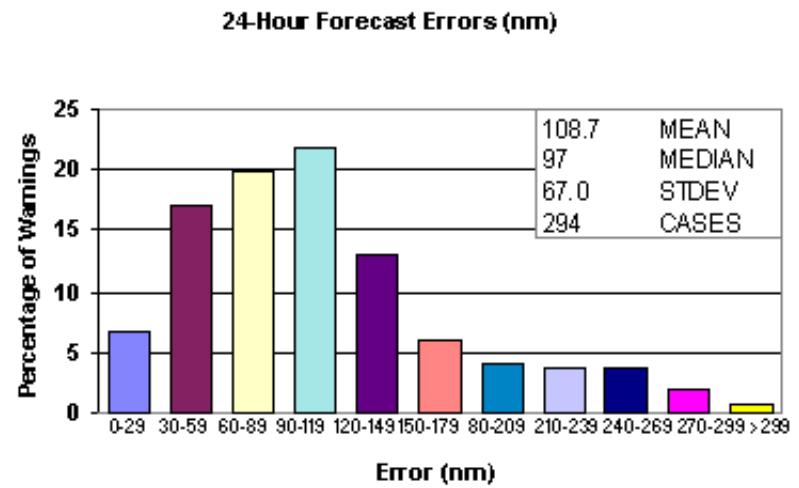


Figure 5-6c. Frequency distribution of 24-hour forecast errors (30 nm increments) for Southwest Pacific and South Indian Ocean tropical cyclones in 1998.

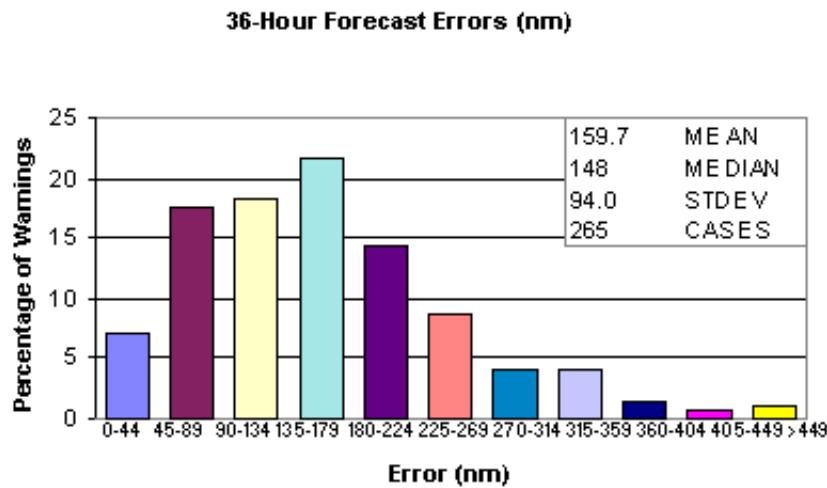


Figure 5-6d. Frequency distribution of 36-hour forecast errors (45 nm increments) for Southwest Pacific and South Indian Ocean tropical cyclones in 1998.

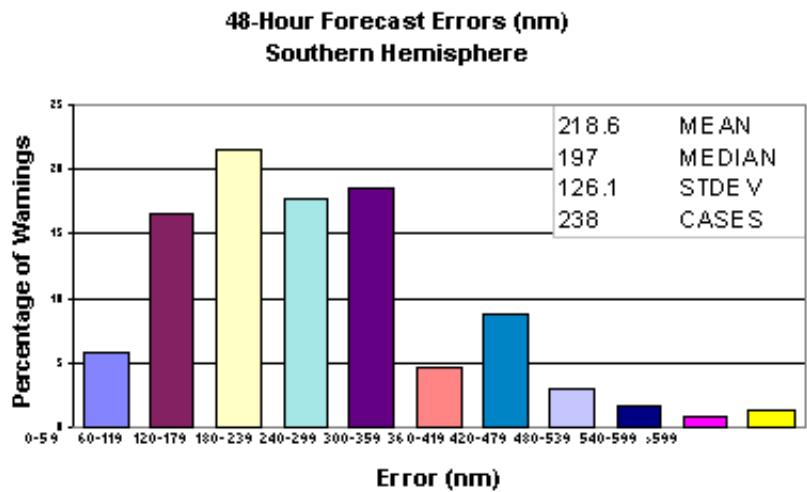


Figure 5-6e. Frequency distribution of 48-hour forecast errors (60 nm increments) for Southwest Pacific and South Indian Ocean tropical cyclones in 1998.

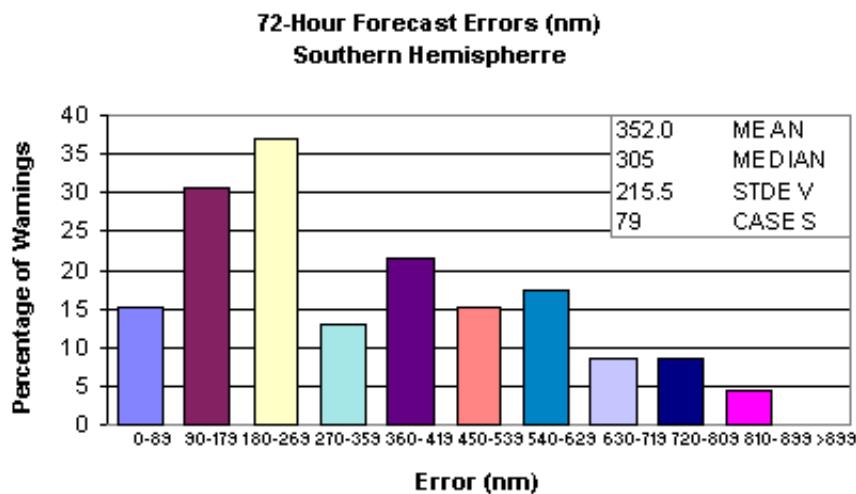


Figure 5-6f. Frequency distribution of 72-hour forecast errors (90 nm increments) for Southwest Pacific and South Indian Ocean tropical cyclones in 1998.

Table 5-4 JTWC INITIAL POSITION AND FORECAST ERRORS (NM) FOR THE SOUTHERN HEMISPHERE 1984-1998

Initial Position	24-Hour				48-Hour				72-Hour					
	Number	Error	Number	Track	Along	Cross	Number	Track	Along	Cross	Number	Track	Along	Cross
1984	301	36	252	133	90	79	191	231	159	134				
1985	306	36	257	134	92	79	193	236	169	132				
1986	279	40	227	129	86	77	171	262	169	164				
1987	189	46	138	145	94	90	101	280	153	138				
1988	204	34	99	146	98	83	48	290	246	144				
1989	287	31	242	124	84	73	186	240	166	136				
1990	272	27	228	143	105	74	177	263	178	152				
1991	264	24	231	115	75	69	185	220	152	129				
1992	267	28	230	124	91	64	208	240	177	129				
1993	257	21	225	102	74	57	176	199	142	114				
1994	386	28	345	115	77	68	282	224	147	134				
1995	245	24	222	108	82	55	175	198	144	108	53	291	169	190
1996	343	24	298	125	90	67	237	240	174	129	46	277	221	133
1997	561	24	499	109	82	72	442	210	163	135	150	288	248	175
1998	329	26	305	111	85	52	245	219	169	108	81	349	261	171
15Yr														
Avg	299	30	253	124	87	71	201	237	167	132	83*	301*	224*	167*
*4-year average														

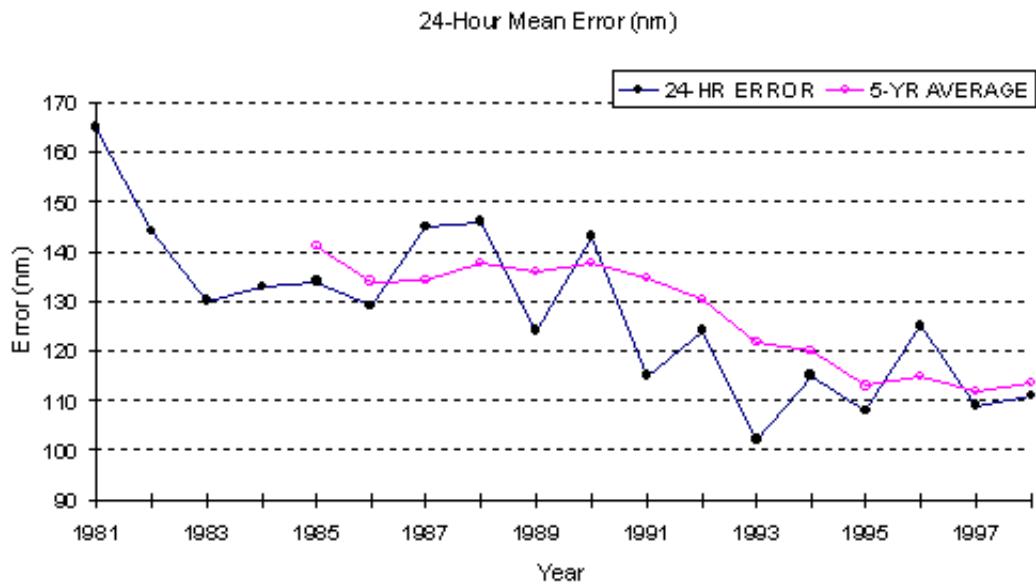


Figure 5-7a. Mean track forecast error (nm) and 5-year running mean for 24 hours for Southern Hemisphere (Africa to 180 degrees) tropical cyclones from 1981-1998.

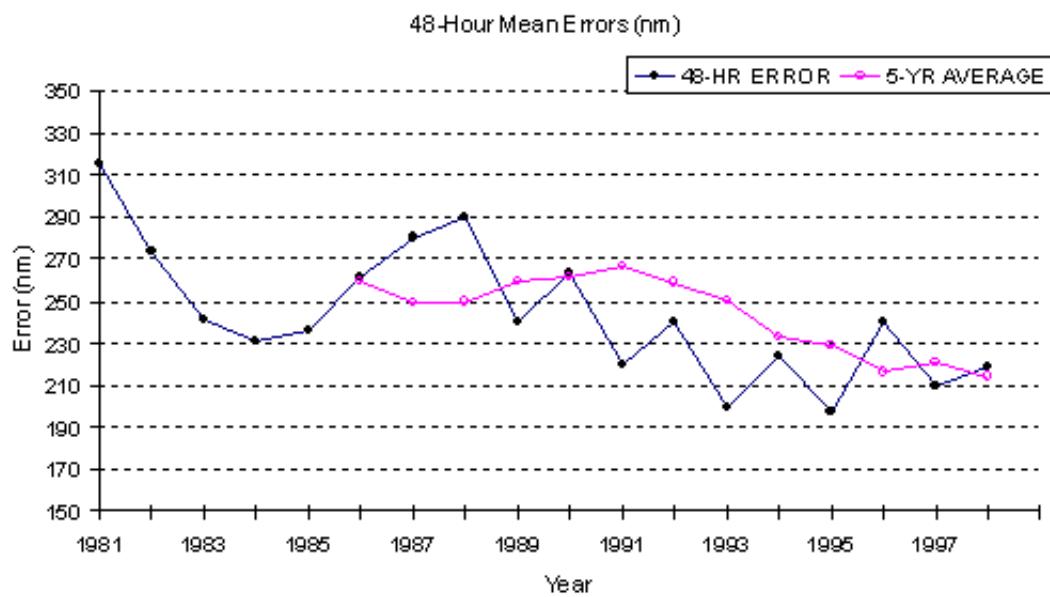


Figure 5-7b. Mean track forecast error (nm) and 5-year running mean for 48 hours for Southern Hemisphere (Africa to 180 degrees) tropical cyclones from 1981-1998.

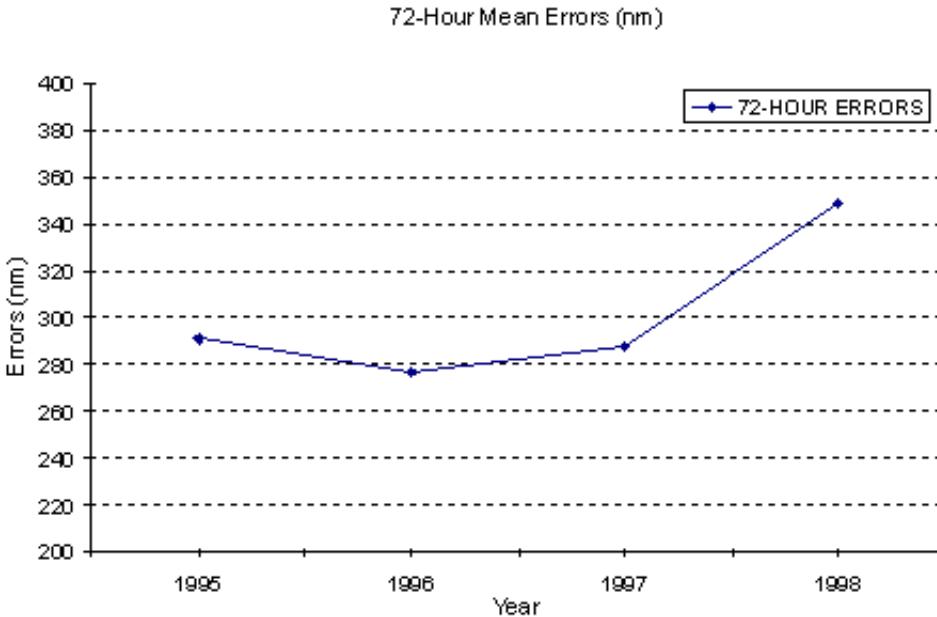


Figure 5-7c. Mean track forecast error (nm) and 5-year running mean for 72 hours for Southern Hemisphere (Africa to 180 degrees) tropical cyclones from 1981-1998. The 72-hour chart was added this year.

5.2 COMPARISON OF OBJECTIVE AIDS

JTWC uses a variety of objective aids for guidance in the warning preparation process. Multiple aids are required, because each aid has particular strengths and weaknesses which vary by basin, numerical model initialization, time of year, synoptic situation and forecast period. The accuracy of objective aid forecasts depends on both the specified position and the past motion of the tropical cyclone as determined by the working best track. JTWC initializes its objective aids using an extrapolated working best track position, called a "bogus", so the output of the aid will start at the valid time of the next warning initial position.

Unless stated otherwise, all of the objective aids discussed below run in all basins covered by JTWC's AOR and routinely provide forecast positions at 12-, 24-, 36-, 48-, and 72-hours. The aids can be divided into five general categories: extrapolation, climatology and analogs, statistical, dynamic, and hybrids.

5.2.1 EXTRAPOLATION (XTRP)

Past speed and direction are computed using the rhumb line distance between the current and 12-hour old positions of the tropical cyclone. Extrapolation from the current warning position is used to compute forecast positions.

5.2.2 CLIMATOLOGY and ANALOGS

5.2.2.1 CLIMATOLOGY (CLIM)

Employs time and location windows relative to the current position of the tropical cyclone to determine which historical storms will be used to compute the forecast. The historical database is from 1945-1981 for the Northwest Pacific, and from 1900 to 1990 for the rest of JTWC's AOR. Objective intensity forecasts are available from these databases. Scatter diagrams of expected tropical cyclone motion at bifurcation points are also available from these databases.

5.2.2.2 ANALOG

A revised Typhoon Analog 1993 (TYAN93) picks the top matches with the basin climatology of historical tropical cyclone best tracks. Matches are based upon the differences between the direction and speed of the superimposed historical best track positions and the past direction and speed of the cyclone. Specifically, the directions and speeds are calculated from the 12-hour old position to the current "fix" position and the 24-hr old position to the "fix" position. Separate comparisons are made for climatology cyclone tracks classified as "straight," "recurver" and "other". There is also a "total" group, that includes the top matches without regard to classification of tracks.

TYAN93 works in the same manner for all basins. The time-window is +/- 35 days from the "fix." The space-window is +/- 2.5 degrees latitude and +/- 5 degrees longitude from the "fix" position on the first pass of each forecast. The maximum-wind-speed window is as follows (for basins with climatology wind speeds):

- a. If "fix" wind speed is \leq 25 kt, (13 m/s) climatology cyclone wind speed must be \geq 30 kt. (15 m/s)
- b. If "fix" wind speed is 30 kt, (15 m/s) climatology cyclone wind speed must be in range from 25 to 35 kt. (13 to 17 m/s)
- c. If "fix" wind speed is \geq 35 kt (17 m/s), climatology cyclone wind speed must be at least 35 kt. (17 m/s).

Matching is based upon weighted direction and speed errors. Forecasting is based upon "straight" and "recurver" type climatology tropical cyclones, where the 12-hour and 24-hour best "straight" ("recurver") matches are combined into one set of best matches for "straight" ("recurver").

5.2.3 STATISTICAL

5.2.3.1 CLIMATOLOGY AND PERSISTENCE (CLIPER or CLIP)

A statistical regression technique based on climatology, current position and 12-hour and 24-hour past movement. This technique is the baseline against which forecast skill is measured. CLIP in the western North Pacific uses third-order regression equations, and is based on the work of Xu and Neumann (1985). CLIPER has been available outside this basin since mid-1990, with regression coefficients recently recomputed by FNMOC based on the updated 1900-1989 database.

5.2.3.2 COLORADO STATE UNIVERSITY MODEL (CSUM)

A statistical-dynamical technique based on the work of Matsumoto (1984). Predictor parameters include the current and 24-hr old position of the storm, heights from the current and 24-hr old NOGAPS 500-mb

analyses, and heights from the 24-hr and 48-hr NOGAPS 500-mb prognoses. Height values from 200-mb fields are substituted for storms that have an intensity exceeding 90 kt and are located north of the subtropical ridge. Three distinct sets of regression equations are used depending on whether the storm's direction of motion falls into "below", "on", or "above" the subtropical ridge categories. During the development of the regression equation coefficients for CSUM, the so-called "perfect prog" approach was used, in which verifying analyses were substituted for the numerical prognoses that are used when CSUM is run operationally. Thus, CSUM was not "tuned" to any particular version of NOGAPS, and in fact, the performance of CSUM should presumably improve as new versions of NOGAPS improve. CSUM runs only in the western North Pacific, South China Sea, and North Indian Ocean basins.

5.2.3.3 JTWC92 or JT92

JTWC92 is a statistical-dynamical model for the North West Pacific Ocean basin which forecasts tropical cyclone positions at 12-hour intervals to 72 hours. The model uses the deep-layer mean height field derived from the NOGAPS forecast fields. These deep-layer mean height fields are spectrally truncated to wave numbers 0 through 18 prior to use in JTWC92. Separate forecasts are made for each position. That is, the forecast 24-hour position is not a 12-hour forecast from the forecasted 12-hour position.

JTWC92 uses five internal sub-models which are blended and iterated to produce the final forecasts. The first sub-model is a statistical blend of climatology and persistence, known as CLIPER. The second sub-model is an analysis mode predictor, which only uses the "analysis" field. The third sub-model is the forecast mode predictor, which uses only the forecast fields. The fourth sub-model is a combination of 1 and 2 to produce a "first estimate" of the 12-hourly forecast positions. The fifth sub-model uses the output of the "first estimate" combined with 1, 2, and 3 to produce the forecasts. The iteration is accomplished by using the output of sub-model 5 as though it were the output from sub-model 4. The optimum number of iterations has been determined to be three.

When JTWC92 is used in the operational mode, all the NOGAPS fields are forecast fields. The 00Z and 12Z tropical forecasts are based upon the previous 12-hour old synoptic time NOGAPS forecasts. The 06Z and 18Z tropical forecasts are based on the previous 00Z and 12Z NOGAPS forecasts, respectively. Therefore, operationally, the second sub-model uses forecast fields and not analysis fields.

5.2.4 DYNAMIC

5.2.4.1 NOGAPS VORTEX TRACKING ROUTINE (NGPS/X)

Tropical cyclone vortices are tracked in NOGAPS by converting the 1000-mb u and v wind component fields into isogons. The intersection of isogons are either the center of a cyclonic or anticyclonic circulation, or a col. The tracking program starts at the last known location of the cyclone - a warning position. Based on this position and the last known speed and direction of movement, the program hunts for the next cyclonic center representing the tropical cyclone. Confidence factors are generated within the program and are modified, as required, by a quality control program that formats the data for transmission.

5.2.4.2 GEOPHYSICAL FLUID DYNAMICS MODEL - NAVY (GFDN)

This model is an adaptation of the Geophysical Fluid Dynamics Model used by the National Center for Environmental Prediction (NCEP). This model uses a triple-nested movable mesh with 18 sigma levels. The

outer mesh domain covers a 75 degrees x 75 degrees area with a horizontal resolution of 1 degree and is fixed for the duration of the model run based on the initial location and movement of the tropical cyclone. The 10 degrees x 10 degrees middle and a 5 degrees x 5 degrees inner (resolution 1/6 degrees) nested meshes move with the cyclone. Based on the global analysis and an initialization message, the TC is removed from the global analysis, and replaced by a synthetic vortex which has an asymmetric (beta-advection) component added. Boundary conditions are updated periodically from forecast fields generated by a global forecast model. In addition to standard output fields, the model outputs TC track forecasts and maximum isotach swaths indicating the location of maximum winds in relation to the TC track.

5.2.4.3 FNMOC BETA AND ADVECTION MODEL (FBAM)

This model is an adaptation of the Beta and Advection model used by the National Center for Environmental Prediction (NCEP). The forecast motion results from a calculation of environmental steering and an empirical correction for the observed vector difference between that steering and the 12-hour old storm motion. The steering is computed from the NOGAPS Deep Layer Mean (DLM) wind fields which are a weighted average of the wind fields computed for the 1000-mb to 100-mb levels. The difference between past storm motion and the DLM steering is treated as if the storm were a Rossby wave with an "effective radius" propagating in response to the horizontal gradient of the coriolis parameter, beta. The forecast proceeds in one-hour steps, recomputing the effective radius as beta changes with storm latitude, and blending in a persistence bias for the first 12 hours.

5.2.5 HYBRIDS

5.2.5.1 HALF PERSISTENCE AND CLIMATOLOGY (HPAC)

Forecast positions generated by equally weighting the forecasts given by XTRP and CLIM.

5.2.5.2 DYNAMIC AVERAGE (DAVE)

A simple average of all dynamic forecast aids: NOGAPS (NGPS), Bracknell (EGRR), JMA Typhoon Model (JTYS), JT92, FBAM, and CSUM.

5.3 TESTING AND RESULTS

A comparison of selected techniques is included in Table 5-5 for all western North Pacific tropical cyclones, Table 5-6 for all North Indian Ocean tropical cyclones and Table 5-7 for the Southern Hemisphere. For example, in Table 5-5 for the 12-hour mean forecast error, 173 cases available for a homogeneous comparison, the average forecast error at 12 hours was 72 nm for NGPS and 61 nm for JTWC. The difference of 11 nm is shown in the lower right. Differences are not always exact, due to computational round-off.

Table 5-5 1998 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTHWEST PACIFIC

12-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS	FBAM	CSUM	EGRR	GFDN	JGSM	JTYM	CLIP	DAVE	RJTD
JTWC	420	68									
	68	0									
NGPS	173	61	176	73							
	72	11	73	0							
FBAM	412	68	175	73	438	71					
	69	1	64	-9	71	0					
CSUM	321	65	162	68	333	67	333	69			
	68	3	63	-5	69	2	69	0			
EGRR	4	32	3	44	4	41	4	60	4	144	
	144	112	163	119	144	103	144	84	144	0	
GFDN	158	68	0	0	155	68	102	70	1	87	158
	72	4	0	0	72	4	71	1	106	19	72
JGSM	112	61	101	63	112	63	106	69	3	163	5
	62	1	59	-4	62	-1	62	-7	43	-120	95
JTYM	116	65	2	63	115	66	80	69	0	0	101
	61	-4	98	35	61	-5	56	-13	0	0	61
CLIP	420	68	175	73	438	71	333	69	4	144	158
	71	3	65	-8	73	2	70	1	40	-104	72
DAVE	369	65	157	71	384	69	305	68	4	144	142
	66	1	60	-11	67	-2	64	-4	43	-101	65
RJTD	9	53	5	85	9	54	4	55	0	0	3
	80	27	96	11	80	26	82	27	0	0	47
									-22	118	2
									118	0	65
									-15	80	32
									79	37	80
									0		
24-HOUR MEAN FORECAST ERROR (NM)											
	JTWC	NGPS	FBAM	CSUM	EGRR	GFDN	JGSM	JTYM	CLIP	DAVE	RJTD
JTWC	375	124									
	124	0									
NGPS	163	116	166	119							
	118	2	119	0							
FBAM	369	125	165	119	396	126					
	125	0	122	3	126	0					
CSUM	289	123	153	114	302	127	302	135			
	135	12	128	14	135	8	135	0			
EGRR	153	121	139	120	157	124	141	134	168	119	
	116	-5	113	-7	119	-5	109	-25	119	0	
GFDN	139	125	0	0	136	115	90	140	3	155	139
	103	-22	0	0	103	-12	106	-34	100	-55	103
JGSM	106	122	99	106	106	115	101	142	94	104	5
	96	-26	92	-14	95	-20	95	-47	96	-8	185
									-8	96	0

Table 5-5 1998 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTHWEST PACIFIC

JTYM	112	131	2	136	111	116	78	152	4	176	96	103	8	141	114	93
	94	-37	121	-15	93	-23	87	-65	99	-77	90	-13	114	-27	93	0
CLIP	375	124	165	119	396	126	302	135	159	118	139	103	107	96	114	93
	134	10	129	10	136	10	133	-2	135	17	135	32	136	40	143	50
DAVE	331	121	149	117	348	124	277	135	141	114	126	103	99	97	103	95
	117	-4	111	-6	118	-6	118	-17	118	4	113	10	113	16	117	22
RJTD	210	125	100	114	209	117	173	144	99	101	94	102	90	97	92	93
	101	-24	102	-12	102	-15	103	-41	103	2	98	-4	103	6	101	8

36-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS	FBAM	CSUM	EGRR	GFDN	JGSM	JTYM	CLIP	DAVE	RJTD	
JTWC	322	178										
	178	0										
NGPS	137	175	141	168								
	165	-10	168	0								
FBAM	316	179	140	167	348	187						
	185	6	188	21	187	0						
CSUM	243	179	133	163	259	192	259	206				
	209	30	204	41	206	14	206	0				
EGRR	1	81	1	47	1	79	1	36	1	252		
	252	171	252	205	252	173	252	216	252	0		
GFDN	118	173	0	0	116	173	73	219	0	0	119	
	136	-37	0	0	134	-39	134	-85	0	0	136	
JGSM	98	188	92	158	99	185	95	234	1	252	4	
	132	-56	130	-28	130	-55	130	-104	70	-182	174	
JTYM	101	190	2	191	100	178	69	238	0	0	85	
	139	-51	159	-32	137	-41	132	-106	0	0	131	
CLIP	322	178	140	167	348	187	259	206	1	252	119	
	202	24	201	34	203	16	201	-5	76	-176	208	
DAVE	285	178	128	168	307	184	238	208	1	252	109	
	172	-6	172	4	172	-12	173	-35	76	-176	168	
RJTD	6	128	2	144	6	187	3	185	0	0	80	-36
	105	-23	86	-58	105	-82	109	-76	0	0	68	1
												68

48-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS	FBAM	CSUM	EGRR	GFDN	JGSM	JTYM	CLIP	DAVE	RJTD
JTWC	273	239									
	239	0									
NGPS	118	230	122	219							
	218	-12	219	0							
FBAM	268	241	121	217	305	258					
	260	19	252	35	258	0					
CSUM	208	243	115	215	228	267	228	288			

Table 5-5 1998 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTHWEST PACIFIC																						
	295	52	290	75	288	21	288	0														
EGRR	114	237	99	229	118	260	109	301	128	200												
	197	-40	192	-37	199	-61	198	-103	200	0												
GFDN	104	231	0	0	105	244	63	294	3	174	108	180										
	183	-48	0	0	178	-66	170	-124	187	13	180	0										
JGSM	92	258	81	210	92	267	89	335	81	197	4	217	93	178								
	180	-78	178	-32	175	-92	176	-159	174	-23	238	21	178	0								
JTYM	90	258	1	252	90	251	59	331	3	202	77	187	6	198	93	178						
	180	-78	223	-29	179	-72	170	-161	293	91	173	-14	157	-41	178	0						
CLIP	273	239	121	217	305	258	228	288	120	198	108	180	93	178	93	178	315	278				
	277	38	271	54	276	18	274	-14	270	72	279	99	294	116	296	118	278	0				
DAVE	244	245	109	219	270	254	210	293	107	198	99	180	87	179	84	184	270	279	270			
	237	-8	235	16	233	-21	238	-55	246	48	226	46	257	78	242	58	233	-46	233			
RJTD	145	254	67	230	144	268	115	351	66	202	67	188	67	182	67	172	146	295	137			
	201	-53	203	-27	199	-69	192	-159	217	15	185	-3	205	23	191	19	199	-96	203			
72-HOUR MEAN FORECAST ERROR (NM)																						
	JTWC		NGPS		FBAM		CSUM		EGRR		GFDN		JGSM		JTYM		CLIP		DAVE		RJTD	
JTWC	202	370																				
	370	0																				
NGPS	76	361	80	334																		
	332	-29	334	0																		
FBAM	198	369	79	331	225	418																
	435	66	380	49	418	0																
CSUM	150	370	75	334	164	426	164	512														
	541	171	483	149	512	86	512	0														
EGRR	82	398	64	345	84	446	79	585	93	349												
	350	-48	326	-19	359	-87	355	-230	349	0												
GFDN	76	359	0	0	76	427	44	510	0	0	78	322										
	329	-30	0	0	319	-108	298	-212	0	0	322	0										
JGSM	68	395	50	343	68	461	66	608	60	356	4	444	69	264								
	267	-128	244	-99	251	-210	250	-358	236	-120	465	21	264	0								
JTYM	67	401	1	761	66	458	43	607	1	821	56	336	6	413	68	270						
	270	-131	644	-117	271	-187	269	-338	644	-177	254	-82	275	-138	270	0						
CLIP	202	370	79	331	225	418	164	512	86	358	78	322	69	264	68	270	232	414				
	420	50	422	91	411	-7	406	-106	424	66	432	110	430	166	449	179	414	0				
DAVE	184	379	73	340	203	419	156	525	79	356	73	322	65	256	65	274	203	419	203	393		
	408	29	375	35	393	-26	395	-130	444	88	398	76	437	181	431	157	393	-26	393	0		
RJTD	106	388	40	356	105	489	85	650	51	396	48	351	49	264	47	261	107	415	101	462	107	
	305	-83	309	-47	296	-193	296	-354	298	-98	292	-59	310	46	301	40	303	-112	302	-160	303	

Table 5-6 1998 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTH INDIAN OCEAN (1 JAN 1998 - 31 DECEMBER 1998)

12-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS		GFDN	OTCM		CLIP	HPAC
JTWC	69	67						
	67	0						
NGPS	36	67	37	89				
	88	21	89	0				
GFDN	26	61	0	0	34	68		
	66	5	0	0	68	0		
OTCM	17	48	6	69	11	64	18	97
	99	51	95	26	101	37	97	0
CLIP	69	67	36	88	28	69	17	99
	71	4	71	-17	64	-5	43	-56
HPAC	69	67	36	88	28	69	17	99
	70	3	71	-17	61	-8	45	-54
							78	78
							-1	0

24-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS		EGRR	GFDN	OTCM		CLIP	HPAC
JTWC	55	106							
	106	0							
NGPS	28	103	30	122					
	119	16	122	0					
EGRR	1	235	0	0	3	643			
	852	617	0	0	643	0			
GFDN	20	102	0	0	1	852	25	121	
	97	-5	0	0	133	-719	121	0	
OTCM	9	103	3	155	0	0	5	115	9
	202	99	224	69	0	0	201	86	202
CLIP	55	106	29	119	2	444	22	118	9
	126	20	122	3	131	-313	124	6	103
HPAC	55	106	29	119	2	444	22	118	9
	118	12	113	-6	142	-302	115	-3	101
							-101	126	-6
							126	0	

Table 5-6 1998 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTH INDIAN OCEAN (1 JAN 1998 - 31 DECEMBER 1998)

36-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS		GFDN		OTCM		CLIP		HPAC	
JTWC	44	145									
	145	0									
NGPS	21	151	23	178							
	174	23	178	0							
GFDN	16	143	0	0	18	183					
	147	4	0	0	183	0					
OTCM	3	118	0	0	2	218	3	217			
	217	99	0	0	244	26	217	0			
CLIP	44	145	22	176	17	170	3	217	57	194	
	194	49	192	16	206	36	152	-65	194	0	
HPAC	44	145	22	176	17	170	3	217	57	194	57
	174	29	173	-3	188	18	124	-93	180	-14	180
											0

48-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS		EGRR		GFDN		OTCM		CLIP		HPAC
JTWC	34	194										
	194	0										
NGPS	16	212	18	202								
	198	-14	202	0								
EGRR	1	324	0	0	3	716						
	971	647	0	0	716	0						
GFDN	13	184	0	0	1	971	14	234				
	199	15	0	0	468	-503	234	0				
OTCM	2	186	0	0	0	0	1	159	2	381		
	381	195	0	0	0	0	597	438	381	0		
CLIP	34	194	17	202	2	515	13	199	2	381	46	262
	276	82	283	81	148	-367	280	81	317	-64	262	0
HPAC	34	194	17	202	2	515	13	199	2	381	46	262
	246	52	250	48	262	-253	253	54	242	-139	241	-21
											241	0

Table 5-6 1998 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTH INDIAN OCEAN (1 JAN 1998 - 31 DECEMBER 1998)

72-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS		EGRR		GFDN	CLIP	HPAC
JTWC	17	262						
		262	0					
NGPS	8	275	10	234				
		220	-55	234	0			
EGRR	0	0	0	0	2	567		
		0	0	0	567	0		
GFDN	8	261	0	0	0	0	8	251
		251	-10	0	0	0	251	0
CLIP	17	262	10	234	1	123	8	251
		415	153	392	158	42	-81	432
HPAC	17	262	10	234	1	123	8	251
		323	61	323	89	184	61	328
						77	311	-48
							311	0

Table 5-7 1998 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE SOUTHERN HEMISPHERE (1 JUL 1997 - 30 JUNE 1998)

12-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS		EGRR		GFDN	OTCM	CLIP	HPAC
JTWC	329	64							
		64	0						
NGPS	225	62	308	83					
		73	11	83	0				
EGRR	6	50	6	108	9	272			
		332	282	332	224	272	0		
GFDN	62	78	33	124	0	0	196	77	
		89	11	108	-16	0	0	77	0
OTCM	182	68	158	89	3	578	181	75	447
		94	26	99	10	74	-504	83	92
CLIP	321	64	265	79	8	279	137	79	331
		98	34	216	137	98	-181	146	67
HPAC	320	64	258	76	8	279	134	78	318
		69	5	67	-9	78	-201	75	-3
							75	-15	73
								-172	73
									0

Table 5-7 1998 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE SOUTHERN HEMISPHERE (1 JUL 1997 - 30 JUNE 1998)

24-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS		EGRR		GFDN	OTCM	CLIP	HPAC
JTWC	305	111							
		111	0						
NGPS	213	109	289	131					
		114	5	131	0				
EGRR	134	105	137	105	178	117			
		109	4	113	8	117	0		
GFDN	58	131	29	225	12	122	187	120	
		136	5	167	-58	176	54	120	0
OTCM	167	113	141	143	61	110	168	116	407 145
		147	34	153	10	130	20	138	22 145 0
CLIP	299	111	252	125	151	113	131	123	302 147 516 305
		148	37	257	132	147	34	199	76 287 140 305 0
HPAC	297	110	245	120	151	112	128	122	291 143 498 285 510 126
		123	13	121	1	116	4	133	11 131 -12 126 -159 126 0

36-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS		EGRR		GFDN	OTCM	CLIP	HPAC
JTWC	273	161							
		161	0						
NGPS	186	160	257	178					
		159	-1	178	0				
EGRR	5	70	5	97	7	389			
		471	401	471	374	389	0		
GFDN	52	187	21	362	0	0	171	162	
		173	-14	207	-155	0	0	162	0
OTCM	142	169	113	187	3	744	139	161	336 220
		228	59	228	41	200	-544	217	56 220 0
CLIP	269	162	227	170	6	416	119	164	254 222 473 346
		202	40	297	127	175	-241	257	93 320 98 346 0
HPAC	267	161	220	163	6	416	116	163	246 218 457 327 469 182
		181	20	178	15	130	-286	197	34 188 -30 182 -145 182 0

Table 5-7 1998 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE SOUTHERN HEMISPHERE (1 JUL 1997 - 30 JUNE 1998)

48-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS	EGRR	GFDN	OTCM	CLIP	HPAC
JTWC	245	219					
	219	0					
NGPS	164	215	225	227			
	208	-7	227	0			
EGRR	102	215	101	193	141	195	
	183	-32	187	-6	195	0	
GFDN	45	252	16	497	5	214	155
	204	-48	249	-248	250	36	206
OTCM	102	244	75	240	31	197	100
	306	62	315	75	297	100	290
CLIP	241	221	201	218	119	183	108
	261	40	323	105	266	83	303
HPAC	239	219	196	211	119	182	105
	248	29	239	28	236	54	267
					62	260	-41
						245	-113
						244	0

72-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS	EGRR	GFDN	OTCM	CLIP	HPAC
JTWC	81	349					
	349	0					
NGPS	39	325	175	319			
	317	-8	319	0			
EGRR	18	308	76	307	117	272	
	268	-40	284	-23	272	0	
GFDN	31	356	10	646	3	315	120
	289	-67	267	-379	321	6	320
OTCM	30	403	50	379	21	321	54
	456	53	483	104	433	112	411
CLIP	80	352	156	314	96	266	84
	337	-15	395	81	390	124	416
HPAC	80	352	154	307	97	265	84
	416	64	378	71	366	101	429
					101	418	-37
						380	-39
						380	0